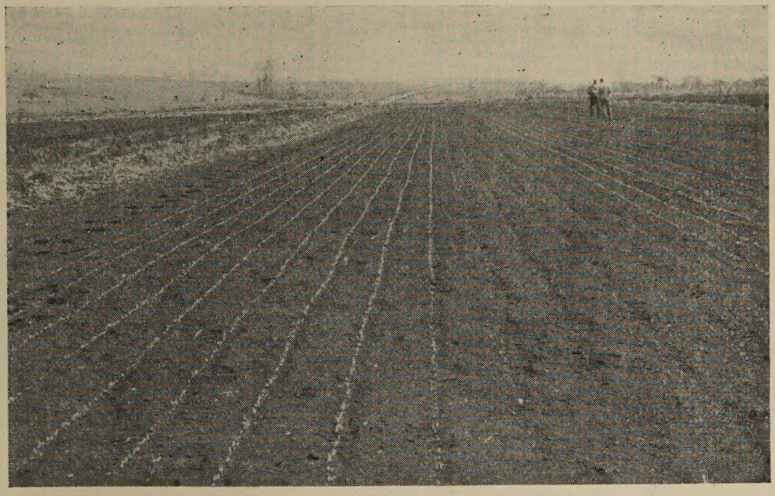
Bulletin 566 June, 1933

IMPERIAL MYCOLOGICAL INSTITUTE
6 NOV. 1933

Copper Seed Treatments for the Control of Damping-Off of Spinach

P. P. Pirone, A. G. Newhall, W. W. Stuart, J. G. Horsfall, and A. L. Harrison



The value of spinach-seed treatment is well illustrated by comparison of the stand in the nine cuprous-oxide-treated rows on the left with that in the five untreated rows on the right

Published by the
Cornell University Agricultural Experiment Station
Ithaca, New York

Received for publication May 16, 1933

CONTENTS

	PAGE
The crop	3
Losses from damping-off	3
Varietal susceptibility	4
The disease	4
Symptoms	4
Causal organism	4
Contributing factors	6
Control measures	7
Seed treatments	7
The copper-sulfate-soak method	7
The red-oxide-of-copper-dust treatment	7
Methods of obtaining data	9
Stand and yield data	9
Tests on mineral soils of Nassau County	9
Muck-land tests	13
Wayne County experiments in 1931	13
Wayne County experiments in 1932	15
Experiments in Genesee and Orleans Counties in 1932	16
Cost of treatments	19
Other materials tried and discarded	19
Effect of the copper seed treatments on other plant diseases	20
Discussion	20
Practical suggestions	23
Summary	24
References cited	25

COPPER SEED TREATMENTS FOR THE CONTROL OF DAMPING-OFF OF SPINACH

P. P. Pirone, A. G. Newhall, W. W. Stuart,
J. G. Horsfall, and A. L. Harrison[1]

THE CROP

Recent discoveries of the importance of spinach in the diet have focused attention on the great value of this crop, and are doubtless the main cause of the recent large increases in the acreage devoted to its culture.

Spinach is raised on the mineral soils of Long Island and elsewhere as a market-garden crop, and on the muck lands of western New York as a canning crop. Nearly 3000 acres are devoted to this crop in Nassau County alone. Early-spring crops on the muck lands are often followed by summer or fall crops, while on Long Island as many as four crops a year are grown. Winter crops are sometimes produced under glass in the hothouse districts.

LOSSES FROM DAMPING-OFF

Losses from damping-off vary from almost nothing to 100 per cent. Frequently the stand is so thin and ragged that the grower plows or disks the crop under. Not only does a thin stand reduce the yield, but the low, more spreading, habit of growth which unevenly spaced plants quickly assume results in more dirt being picked up at harvest time. This, in turn, often leads to dockage at the canning factory because of the extra labor required to hand-pick the crop. A crop that has much damping-off in the seedling stage is more likely to have many partly stunted yellowish plants at harvest, which is another cause of dockage at the canning factory. Some growers, expecting a poor stand at the usual rate of sowing, have acquired the habit of planting from 20 to 50 per cent more seed than is ordinarily recommended. If damping-off is no factor and the seed all comes up, then the plants are so thick that they fail to reach proper size. In such cases they may shoot to seed prematurely and develop many yellow leaves, so that the yield is very unsatisfactory.

Canners, particularly, have expressed the need of a method that would give a uniform stand of healthy, properly spaced plants, regardless of the weather or of the particular field in which the crop is sown. It is partly in response to this demand that the treatments here described were developed.

Careful estimates of losses to the crop in Nassau County, where nearly 3000 acres are grown, indicate that from 20 to 35 per cent is a conserva-

[1] Dr. J. G. Horsfall, associate in research at the New York Agricultural Experiment Station at Geneva, collaborated in some of the muck experiments conducted in this study. Dr. A. G. Newhall, of Cornell University, did likewise, and assumed the responsibility of interpreting all the data and of preparing the manuscript. Acknowledgment is due the Nassau County Farm Bureau Association whose fellowship was held by P. P. Pirone, the Genesee-Orleans Vegetable Growers' Cooperative Association whose fellowship was held by W. W. Stuart, and the Williamson Cooperative Vegetable Growers' Association whose fellowship was held by A. L. Harrison. Thanks are extended also to the W. N. Clark Company, of Holcombe, New York, and to Dr. Fred W. Geise, of the American Can Company, for their cooperation.

tive figure. This probably means a monetary loss in that county alone of between $75,000 and $150,000 annually. Similar losses occur more or less regularly on the muck lands.

VARIETAL SUSCEPTIBILITY

During the past two years a number of varieties of spinach, including all of the principal commercial sorts grown in the East, have been tested, but none has proved resistant to damping-off. Those tested include King of Denmark, Giant Thick Leaf, Giant Nobel, Giant Prickly, Bloomsdale Long Standing, Bloomsdale Reselected, Long Standing Savoy, and Virginia Blight Resistant Savoy.

Observations indicate that the vitality of a given seed lot is of far more importance than the variety in determining how successfully it will escape decimation by the damping-off fungi during the germination and seedling periods.

THE DISEASE

SYMPTOMS

The usual symptoms of damping-off are too well known to need describing here. It is important to draw attention, however, to the distinction which Horsfall (1932 a) has made between the pre-emergence and the post-emergence types, or phases, of this disease.

In the pre-emergence phase of damping-off, the young seedling is killed before it has reached the surface of the ground. Frequently death and decay set in even before the hypocotyl has emerged from the cracked seedcoat. This is the type of damping-off that is controlled most readily by the seed treatments to be described. Growers who never take the trouble to dig up a number of seeds after they have had ample time to germinate, may remain quite unaware of the losses they are sustaining. They take their poor stands for granted, considering them normal. Some, of course, blame them on "poor seed," not realizing that the best of seed may be rotted by damping-off organisms that reside in the soil.

It was gratifying to find, in the course of these studies, that the ordinary post-emergence toppling-over and death of seedlings already above ground was controlled to a considerable degree by chemicals applied to the seed.

CAUSAL ORGANISM

A species of Pythium referred by Drechsler to *P. ultimum*[2] has been isolated frequently from diseased seedlings. Its pathogenicity has been proved and its residence in the muck land demonstrated (figure 1 and cover illustration). When seeds that fail to germinate, or seedlings that fail to reach the surface of the ground, are removed and cultured in the laboratory, a number of species of Fusaria also, in addition to *Pythium ultimum*, are commonly found. However, in greenhouse tests only the Pythium has proved to be pathogenic.

This Pythium is evidently widely distributed over New York in both

[2] Letter to A. G. Newhall, dated November 22, 1932. Dr. Drechsler points out that this species seems to be the most generally parasitic member of the genus, and that probably it has therefore been designated as *P. debaryanum* very frequently.

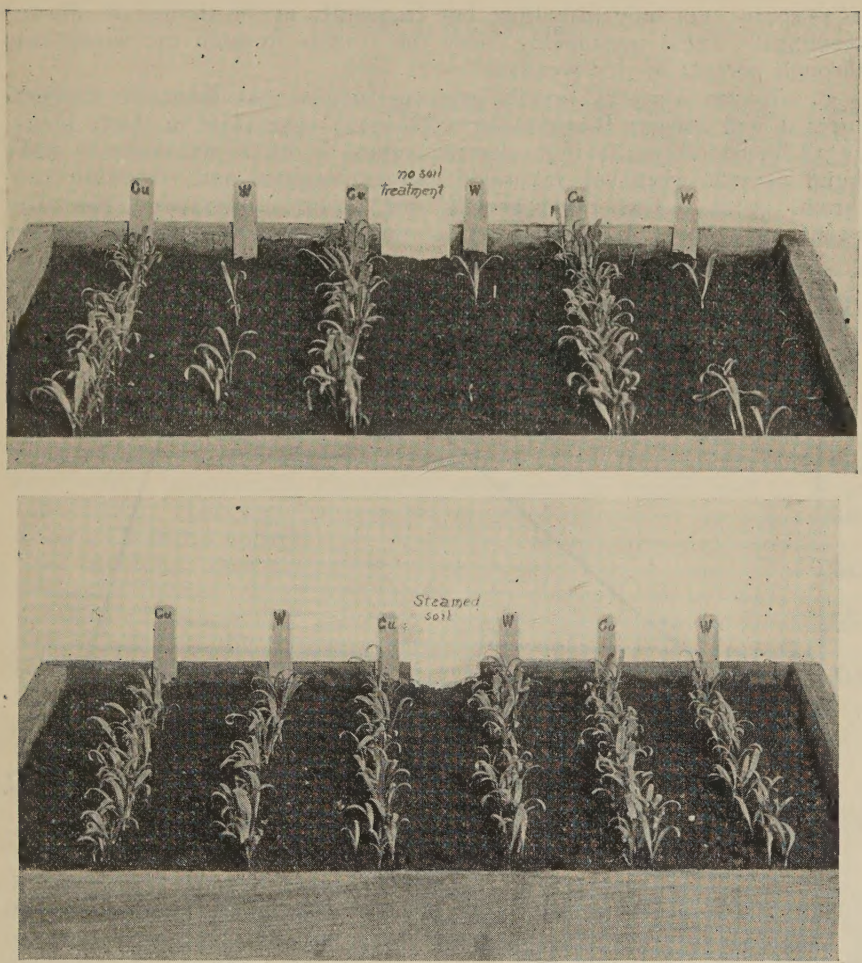


FIGURE 1. GREENHOUSE SEED-TREATMENT DEMONSTRATION

Upper photograph: Field muck in which every other row (marked *Cu*) was planted with copper-sulfate-soaked seeds, 100 seeds to the row, showing that seed treatment gave protection against pre-emergence damping-off

Lower photograph: Field muck steam-sterilized before planting, but seed treated as in the upper flat, showing that the cause of the damping-off was in the soil, not on the seed

In the rows marked *W*, the seed was soaked in water

mineral and muck-land field soil. Also, it is a common cause of damping-off in greenhouse soils of the State. The same fungus is reported as one of the chief causes of damping-off in Ohio by Alexander, Young, and Kiger (1931). It has recently been reported very damaging to spinach in France (Foex, 1931, and Labrousse, 1931) and in Germany (Fahel, 1931).

Fields once infested are known to remain so for a number of years if spinach is annually grown on them. *P. ultimum* produces an abundance

of oospores, not only in culture but frequently in the tissues of affected seedlings. These presumably carry the fungus through the winter and through periods of dry weather.

P. ultimum is a very rapidly growing fungus. At favorable temperatures it will cover a 9-centimeter (3½-inch) agar plate in thirty hours. In all likelihood, much of its destructiveness is due to its ability to make rapid growth whenever favorable soil-temperature and -moisture conditions occur. This rapid growth rate on potato-dextrose agar after twenty-nine hours at various temperatures is shown in figure 2. The

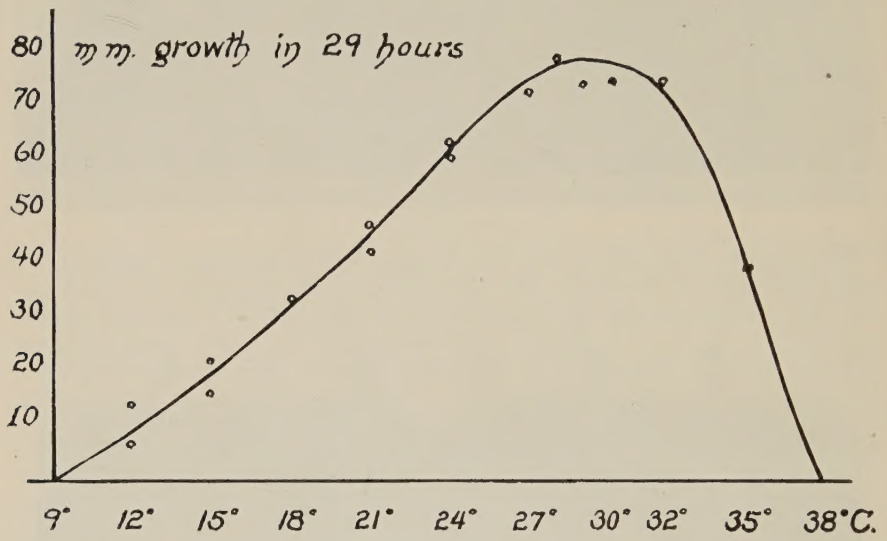


FIGURE 2. GROWTH OF PYTHIUM ULTIMUM AT DIFFERENT TEMPERATURES ON POTATO-DEXTROSE AGAR, pH 6.17

fungus seems to have a rather high and broad optimum range. Excellent growth occurred at 32° C. In several trials, however, no growth occurred at 38° C. and the fungus was killed after two days exposure to this temperature. While no growth was visible in twenty-nine hours at 9° C., nevertheless in a few days the fungus covered the plate at this temperature, and at lower temperatures also it made some growth.

CONTRIBUTING FACTORS

There are two principal factors contributing to the losses from damping-off, besides the mere presence of damping-off fungi in the soil. One of these is wet weather during the period of germination and emergence of the seedlings. The other is low vitality of the seed, which makes it slow to germinate. Losses are minimized when the soil is fairly dry and when the seed is exceptionally vigorous and quick to germinate and grow.[3]

[3] In dry seasons it has been noted repeatedly that the greatest differences between treated and untreated seed lots always occurred on farms where overhead irrigation was employed.

CONTROL MEASURES

SEED TREATMENTS

On finding a Pythium associated with the disease, and from the unpublished work of Townsend[4], the work of McWhorter (1927), that of Coons and Stewart (1927), and particularly that of Horsfall (1930), it was believed that seed treatment with a copper or a mercury fungicide would probably be beneficial. Therefore, since 1929 a large number of experiments have been conducted in different counties of the State by the several authors of this bulletin. These experiments have demonstrated consistently that either of two simple, inexpensive seed treatments with a copper fungicide will give very satisfactory commercial control. The mercury compounds have proved less satisfactory than the copper.

The copper-sulfate-soak method

Excellent control was obtained by soaking the seed in a solution of copper sulfate, 1 or 2 ounces to 1 gallon of water, for approximately one hour, which is essentially the method advocated for tomato seed by Horsfall (1930). The same success has attended its use on the muck lands as on the mineral uplands. No injury has resulted from exposures longer than one hour, even up to twelve hours, and almost none from much stronger solutions. Very good results were obtained also by much weaker solutions (2 ounces in 7 gallons of water). Thus there are ample margins of safety in the method as outlined for spinach. The seed must not be rinsed after treatment. As soon as it has dried sufficiently to pass through the drill, it is ready to be sown, or it may be stored indefinitely after treatment if it is thoroughly dried. This makes the method useful to canners and seedsmen, who may have seed on hand for months.

No special care is needed in the selection of a container in which to do the treating. It is customary to dip the seed while it is still in the original sack. A little agitation is all that is needed, to eliminate all air bubbles and insure complete wetting. A screen door or a window screen supported on sawhorses or boxes makes a convenient drying rack. After drying, the seed should be returned to the sack in which it was treated, or else sown immediately. Approximately 125 pounds of seed may be treated at one time in a barrel containing 30 gallons of solution made by previously dissolving 2 pounds of copper sulfate suspended in a small sack at the surface of the water. Since copper sulfate (blue vitriol) is so inexpensive it is recommended that this solution be discarded after using it twice, although as yet no definite information on the importance of this precaution is at hand. For smaller quantities of seed, such as 10 pounds, 2 ounces of copper sulfate may be dissolved in 2 gallons of water in a large bucket.

The red-oxide-of-copper-dust treatment

Treating seed in a liquid solution obviously requires some labor and time. In the drying process, seed is sometimes spilled on the ground and lost. Allowance usually has to be made for swelling, which may

[4] Report of work conducted under the Oswego County Farm Bureau – Vegetable Growers' Association fellowship for 1929. (Mimeographed.)

introduce an error in sowing. For these reasons there are distinct advantages in a dry seed treatment, which takes only a few minutes to carry out and which does not possess these inconvenient features.

A number of fungicides have been tried during the progress of these investigations, including various sulfur, mercury, and copper compounds. The one which has consistently given the best results is red oxide of copper, or cuprous oxide (Cu_2O), sometimes called *cuprite*. The use of this chemical as a damping-off fungicide was advanced by Horsfall (1932, a and b). It should be pointed out that the black oxide of copper, or cupric oxide (CuO), is of almost no value as a seed-treatment fungicide.

The red oxide has two or three properties which make it of outstanding value in seed treatment. In the first place, it gives results significantly better than those from any other dry treatment, and as good as those obtained by the copper-sulfate-soak method. In the second place, it has sticking properties which make it adhere to the surface of the seed remarkably well. This makes a minimum of shaking necessary to cover each seed thoroughly. In the third place, it is practically insoluble and thus is non-injurious to the tender young spinach seedling as it emerges from the seedcoat, even if it is used in great excess of the amount needed for control.[5] Rains do not dissolve it and wash it away. The bright red color of the fungicide makes it easy to determine when the seed has been thoroughly treated. Finally, its cost is well within the limits of a practical fungicide for this purpose.

In practice, small quantities of seed, up to 10 pounds, may be shaken by hand in any tightly closed container for five minutes with the proper amount of red copper oxide. For best results, the container should be filled not more than half full of seed, and approximately one level teaspoonful of dust should be used to a pound of seed.

As with the copper-sulfate-soak method, there is a wide margin of safety in the amount of copper oxide which can be successfully used. The general practice in these experiments was to use it at the rate of 2 to 6 ounces for 10 pounds of seed. However, 1 ounce of the dust to 10 pounds of seed gave very good results in some experiments. In this connection the length of time devoted to mixing the seed with the dust is of some importance, since, as is obvious, the longer the seed is agitated with a quantity of dust, the more of the dust will be taken up by the seed. More dust than is needed is objectionable, since it may interfere with the proper flow of seed through the drill plate. The results of a test for the proper dosage of red oxide of copper are illustrated in figure 3, in which the stand of

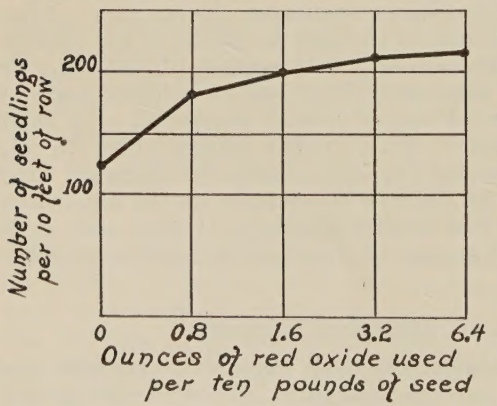


FIGURE 3. EFFECT OF DIFFERENT AMOUNTS OF RED COPPER OXIDE ON STAND OF SEEDLINGS

[5] Celery, lettuce, and a few other vegetables are sometimes injured. More injury may be expected in light, sandy soils than in heavier seedbeds with organic matter present.

seedlings is plotted against the amount of fungicide used per 10 pounds of seed, of the variety King of Denmark. In this test on muck land there was very little advantage in using more than 3 ounces for each 10 pounds of seed, which is a trifle more than one level teaspoonful to a pound of seed. One pound of red oxide contains approximately 65 teaspoonfuls.

METHODS OF OBTAINING DATA

The work of testing various treatments was carried on by the authors, working more or less independently, in five different counties. In this way different phases of the problem could be attacked simultaneously, and different methods of collecting data could be compared.

In most of the experiments, counts of the number of plants which emerged in a unit length of row were made at one or two times during the seedling stage. At the same time a record was usually kept of the number of seedlings that damped off after emerging. This gave data on the control of both the pre-emergence and the post-emergence damping-off. At harvest time, yield data were usually taken either by weighing the spinach from measured plots or by counting the number of 32-quart crates (bushel) from such plots and calculating the yield per acre. In some cases, yields from single pound lots of variously treated seed were compared.

STAND AND YIELD DATA

Tests on mineral soils of Nassau County[6]

In 1931, preliminary tests conducted on two farms showed clearly the value of the copper-sulfate-soak method, 2 ounces to 1 gallon for one hour, as outlined by Horsfall (1930) for tomato seed. The results of these tests are given in tables 1 and 2.

TABLE 1. EFFECT OF THE COPPER-SULFATE-SOAK TREATMENT ON A STAND OF SPINACH ON MINERAL SOIL OF NASSAU COUNTY, LONG ISLAND, 1931

Row	Number of plants in ten 30-foot rows											Per cent increase
	1	2	3	4	5	6	7	8	9	10	Total	
A*												
Plants from treated seed	248	235	290	301	336	190	201	223	249	207	2,480	70
Check plants	167	149	153	207	201	73	83	145	133	146	1,457	
B†												
Plants from treated seed	115	125	117	118	116	109	137	161	115	127	1,240	38
Check plants	86	92	98	79	85	86	97	101	81	92	897	

* Cooperator, William Lindner, Valley Stream, Long Island.
† Cooperator, Joseph Brothers, Valley Stream, Long Island.

With the use of 15 pounds of seed per acre, it was evident that increases of from 30 to 180 crates were made possible merely by treating the seed.

On the basis of these and many more tests, growers and seedsmen, with the aid of the Nassau County Farm Bureau, treated more than 6000 pounds of seed before the season was over. Substantial increases in yield were obtained in nearly every case.

In 1932, at the suggestion of Dr. Horsfall, a series of comparisons were made between the copper-sulfate-soak method and his new dry red-oxide-

[6] Tests made by P. P. Pirone under the Nassau County Farm Bureau Association fellowship.

FIGURE 4. EFFECT OF SEED TREATMENT WITH COPPER SULFATE ON STAND OF PLANTS, UPLAND SOIL IN NASSAU COUNTY

Check plants in foreground, plants from copper-sulfate-treated seed in background

TABLE 2. YIELD FROM 1 POUND OF SPINACH SEED SOAKED IN COPPER-SULFATE SOLUTION, CONTRASTED WITH THAT OF 1 POUND OF UNTREATED SEED SOWN IN ADJACENT ROWS, ON MINERAL SOIL OF NASSAU COUNTY, LONG ISLAND, 1931

	Yield in crates (32-quart)	Per cent increase
A*		
Plants from treated seed	25	56
Check plants	16	
B†		
Plants from treated seed	44	37
Check plants	32	
C‡		
Plants from treated seed	12	20
Check plants	10	

* Cooperator, George Reisert. July 31, 1931.
† Cooperator, George Reisert. October 18, 1931.
‡ Cooperator, George Cornwell. October 18, 1931.

of-copper treatment (1932 b). Semesan dust also was included in the tests. In these experiments the seed was divided into 1-pound lots, each of which was treated as indicated in table 3 and figures 5 and 6. It is evident from these figures, which represent a composite picture of the

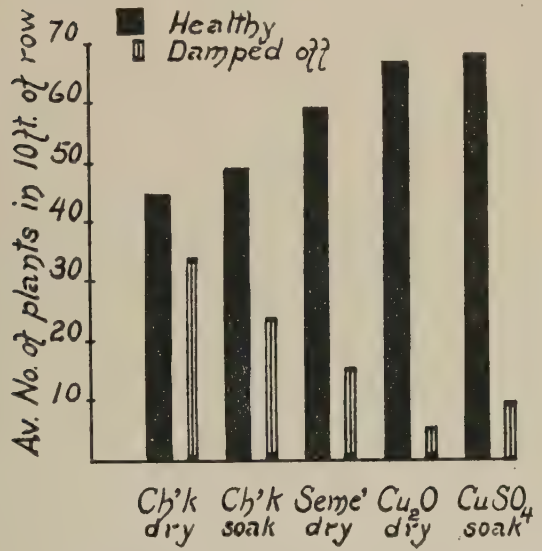


FIGURE 5. CONTROL OF BOTH PRE-EMERGENCE AND POST-EMERGENCE DAMPING-OFF BY COPPER AND ORGANIC-MERCURY SEED TREATMENTS, AS MEASURED BY (A) THE STANDS OF HEALTHY SEEDLINGS AND (B) THE NUMBER OF EMERGED SEEDLINGS WHICH SUBSEQUENTLY DAMPED OFF

(Averages of 7 farm tests in Nassau County made by Pirone in 1932)

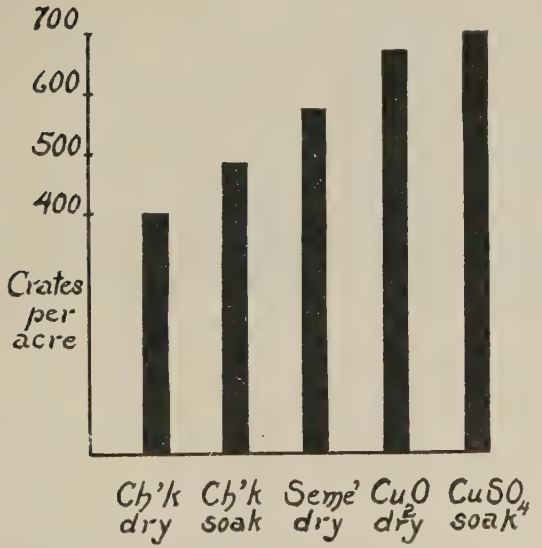


FIGURE 6. RELATIVE EFFECTS OF FOUR SEED TREATMENTS ON DAMPING-OFF CONTROL, AS REFLECTED IN THE YIELDS OF FRESH-CUT SPINACH IN CRATES (32 QUART) PER ACRE

(Averages of 5 farm tests in Nassau County made by Pirone in 1932)

TABLE 3. DETAILED RESULTS OF SEED TREATMENTS ON 7 FARMS IN NASSAU COUNTY, 1932, IN WHICH TWO DRY SEED TREATMENTS WERE COMPARED WITH THE COPPER-SULFATE SOAK

Cooperator, and treatments used	Number of healthy plants emerging from 1 pound of seed*	Number of plants damping off after emerging*	Per cent of plants damping off	Yield, in 32-quart crates (bushels), from 1 pound of seed	Calculated yield, in crates (bushels) per acre	Calculated pounds of seed sown per acre†
Kurzenhauser						
Red oxide of copper	26,652	1,989	6.9	33	376	11.4
Copper-sulfate soak	24,492	2,643	9.7	27	332	12.3
Semesan dry	20,804	6,842	24.7	26.5	302	11.4
Wet check	16,151	12,331	43.3	23	262	11.4
Dry check	12,411	14,320	53.6	13.6	167	12.3
W. Lindner						
Red oxide of copper	22,168	1,974	8.2	38	885	33
Copper-sulfate soak	13,108	4,394	25.1	27.7	664	24
Semesan dry	9,054	4,807	34.7	19	570	30
Wet check	10,095	7,617	43.0	14.5	348	24
Dry check	2,808	12,569	81.7	8	240	30
Joseph Bros.						
Red oxide of copper	16,960	1,895	10.0	52	728	14
Copper-sulfate soak	19,997	2,720	12.0	52	624	12
Semesan dry	17,058	5,030	22.8	50	640	12.8
Wet check	18,055	7,852	30.3	51	535	10.5
Dry check	17,010	4,320	20.2	31	403	13
Reisert						
Red oxide of copper	31,494	5,272	14.3	108	850	8.8
Copper-sulfate soak	28,359	6,486	18.6	128	857	6.7
Semesan dry	35,588	1,960	5.2	131	812	6.2
Wet check	21,997	14,904	40.4	110	770	7
Dry check	21,619	17,149	44.2	105	745	7.1
Rottkamp						
Red oxide of copper	20,301	896	4.2	35	525	15
Copper-sulfate soak	20,389	2,186	9.7	56	1,024	18.3
Semesan dry	13,890	5,297	27.6	29	530	18.3
Wet check	14,044	9,475	40.3	28.7	493	17.2
Dry check	14,999	6,683	30.8	30	516	17.2
Cornwell						
Red oxide of copper	28,957	1,569	5.1	.....	.....	.....
Copper-sulfate soak	32,073	2,416	7.0	.....	.....	.....
Semesan dry	25,341	2,635	9.4	.....	.....	.....
Wet check	27,483	8,616	23.9	.....	.....	.....
Dry check	18,450	7,797	29.7	.....	.....	.....
H. Lindner						
Red oxide of copper	24,473	854	3.4	.....	.....	.....
Copper-sulfate soak	22,738	2,511	9.9	.....	.....	.....
Semesan dry	20,244	3,948	16.3	.....	.....	.....
Wet check	19,430	4,804	19.8	.....	.....	.....
Dry check	16,426	7,977	32.7	.....	.....	.....

* Calculated from careful counts of the number of seedlings in twenty 10-foot strips of row.
† Obtained by dividing the area of an acre by the area covered by 1 pound of seed. Different growers used different sowing rates; also, soaked seed often sows thinner.

average results obtained on 7 farms, (1) that the pre-emergence type of damping-off is controlled on the mineral soils of Long Island about equally well by the copper-sulfate-soak and cuprous-oxide-dust methods, (2) that these treatments are remarkably effective also in controlling the post-emergence damping-off, (3) that Semesan dust also is good, though less effective than the copper treatments, (4) that some benefit may be expected even from soaking the seed in water for an hour, and (5) that substantial increases in yield, of from 50 to 60 per cent, may be expected on the average by the copper treatments.

Muck-land tests

Wayne County experiments in 1931[7]

Since spinach is grown on muck as well as on mineral soil, it was important to know whether the recommendations for Long Island would apply equally well in western New York. In the first year's experiments it was assumed that the deep sowing commonly practiced on the muck,

FIGURE 7. EFFECT OF SEED TREATMENT WITH RED-OXIDE-OF-COPPER DUST, MUCK SOIL IN WAYNE COUNTY

Check plants in foreground, plants from treated seed beginning with the pencil. Another check plot in background
This is the same field as is shown in figure 10 (page 16)

together with the high water-holding, absorptive, and buffer qualities of this kind of soil, would make it wise to use large quantities of the fungicides on the seeds if protection against damping-off was to be secured. This was later found unnecessary. In all but two tests the treatments were made by first moistening the seeds lightly, and then shaking vigorously

[7] Conducted by A. L. Harrison under the Williamson Cooperative Vegetable Growers' Association fellowship.

with the fungicidal dust until all the seeds were thoroughly coated. In the two exceptions formaldehyde solution, 1 pint to 16 gallons of water, was applied with a drip attachment to the drill, as for onion smut.

Abnormally large quantities of the dusts were thus employed, often from 1 to 5 ounces to a pound of seed. The results of these tests, made on three different farms at three different dates in April, May, and June, have been averaged and are summarized in table 4.

TABLE 4. EFFECT OF SEED TREATMENT ON STAND AND ON SUBSEQUENT DAMPING-OFF OF SPINACH IN 15-FOOT ROWS ON MUCK INFESTED WITH PYTHIUM ULTIMUM, 1931

Treatment	Average number of plants emerged	Average per cent damped off
Checks (average of 13)	133	44.0
Formaldehyde solution (applied as for onion smut)	344	6.0
Copper-sulfate monohydrate dust	241	19.1
Calomel dust	202	24.0
Semesan dust	199	11.3
DuBay 738 (ethyl mercury phosphate 2½ per cent)	167	18.3
Yellow oxide of mercury	126	13.7

The best stand and best protection against damping-off were afforded undoubtedly by the use of formaldehyde solution. Copper-sulfate monohydrate dust, Semesan dust, and calomel dust also were helpful. The expense and labor involved ruled formaldehyde out at once as a practical method of control. Further tests were therefore made in August to determine the relative efficiency of calomel and of copper sulfate dry and in solution. As between calomel and copper-sulfate monohydrate dry, it was clearly demonstrated that the latter was greatly preferable. A 90-per-cent stand was obtained with the copper sulfate, as compared with a 22-per-cent stand with calomel and less than 8 per cent in the check. When the dry monohydrate was compared with a dip for an hour in a 0.2-per-cent copper-sulfate solution (2 ounces in 7 gallons), good results were obtained with both, although the solution was a little better as is shown in table 5.

TABLE 5. COMPARISON BETWEEN THE COPPER-SULFATE DIP AND THE MONOHYDRATE DRY SEED TREATMENT

(100 seeds sown in 5 replicated plots. Normal germination, 60 per cent)

Treatment	Actual stand in 5 plots					Average stand
	1	2	3	4	5	
Check	12	16	6	7	10	10.2±1.8
$CuSO_4$ dry, 2 ounces to 3 pounds of seed	40	42	44	36	55	43.2±3.1
$CuSO_4$ dip, ¾ hour, 2 ounces in 7 gallons	41	50	55	46	61	50.6±3.4

The results of these preliminary experiments show what can be expected from seed treatments with copper fungicides on muck lands. They indicate that copper sulfate as a dip is probably the best treatment for spinach seed, and the results with formaldehyde suggest that the organism causing damping-off is soil-borne, like onion smut.

Wayne County experiments in 1932[8]

More extensive field experiments and demonstrations were conducted in Wayne County in the spring of 1932. The following wet and dry treatments were tested on 6 farms on two-year old seed given out by a canning company: copper-sulfate dip, copper-sulfate monohydrate dry, and red oxide of copper dry. The varieties used were Giant Thick Leaf and Morse's Giant Prickly Dark Green.

The results of the treatments on stand and yield have been summarized and are presented in figures 8 and 9. It was clearly evident that both the copper-sulfate soak for one hour in a solution made by dissolving 1 ounce of copper sulfate in 1 gallon of water, and the red-oxide-of-copper-dust treatment in which 2 ounces of dust were thoroughly shaken with 10 pounds of seed, gave very good results. Control of both pre-emergence and post-emergence damping-off was clearly reflected in increased yields. The results with copper-sulfate monohydrate ($CuSO_4$ dry) were not so satisfactory as those with red oxide of copper (Cu_2O) and copper-sulfate soak ($CuSO_4$ soak). This may have been owing to the lesser ability of the monohydrate to

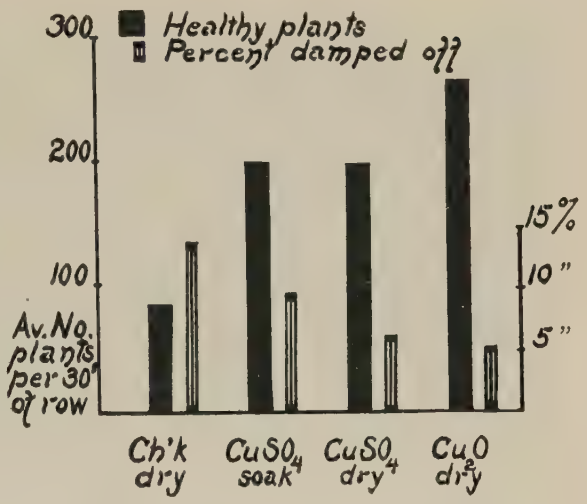


FIGURE 8. CONTROL OF BOTH PRE-EMERGENCE AND POST-EMERGENCE DAMPING-OFF BY SEED TREATMENTS, AS MEASURED BY (A) THE STANDS OF HEALTHY SEEDLINGS (SCALE ON LEFT) AND (B) THE PERCENTAGE OF EMERGED PLANTS WHICH SUBSEQUENTLY DAMPED OFF (SCALE ON RIGHT)

(Averages of 6 muck-land-farm tests in Wayne County made by Newhall in 1932)

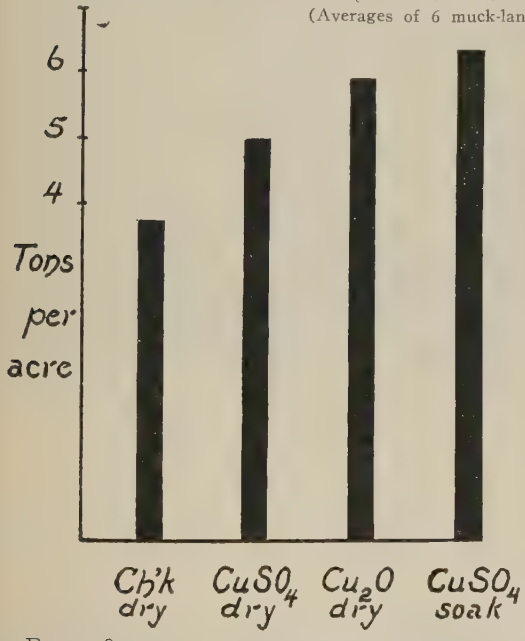


FIGURE 9. RELATIVE EFFECTS OF THREE SEED TREATMENTS ON DAMPING-OFF CONTROL, AS REFLECTED IN THE YIELDS OF FRESH-CUT SPINACH IN TONS PER ACRE

(Averages of 5 muck-land-farm tests in Wayne County made by Newhall in 1932)

[8] Conducted by A. G. Newhall. Acknowledgment is made of the assistance rendered by L. L. Hill, research assistant in entomology at Cornell University, and P. I. Higley, of the Wayne County Farm Bureau, in carrying on these tests.

FIGURE 10. EFFECT OF SEED TREATMENT WITH RED OXIDE OF COPPER DUST, MUCK SOIL IN WAYNE COUNTY, 1932

Upper photograph: A four-row check between two treated lots on muck
Lower photograph: Yield of a plot from treated seed in the four crates on the left, yield of check plot in the two crates on the right

adhere readily to the seed, a quality possessed in marked degree by the red oxide of copper.

Experiments in Genesee and Orleans Counties in 1932[9]

Further tests of several copper and mercurial salts were conducted on the Elba muck in 1932. The red-oxide-of-copper and copper-sulfate-soak

[9] Conducted by W. W. Stuart under the Genesee-Orleans Vegetable Growers' Cooperative Association fellowship.

treatments were compared in these experiments with copper carbonate and copper-lime dust (24–76). Only 1 to 1½ ounces of dust was used on 10 pounds of seed, and only 1 ounce of copper sulfate was dissolved per gallon of water. The principal results of these tests are summarized in tables 6 and 7, and are presented more graphically in figures 11 and 12.

TABLE 6. RELATIVE EFFICIENCY OF SPINACH SEED TREATMENTS AGAINST DAMPING-OFF ON MUCK LAND AS MEASURED BY THE AVERAGE NUMBER OF YOUNG PLANTS PER 30 FEET OF ROW*

(17 tests made in Genesee and Orleans Counties in 1932)

Cooperator and plot number	Check	Copper-sulfate soak	Red oxide of copper	Copper carbonate	Copper-lime dust 24–76	Copper-sulfate monohydrate dust	Semesan dust	Semesan liquid
Teubner								
1	310	421	.....	.....	223	257	404	304
2	195	263	.....	.....	.....	166	.....	.....
3	225	346	.....	.....	.....	234	306	325
4	141	168	156	.....	148	.....	140	149
5	254	235	221	163	.....	.....	.....	249
6	116	190	123	90	101	101	.....	.....
7	139	200	209	177	174	197	.....	.....
8	38	160	119	94	58	56	.....	.....
Parker								
1	69	130	100	99	156	96	.....	.....
2	88	148	144	124	188	107	.....	.....
Clark								
1	201	372	373	356	169	.....	.....	.....
Winsinger & Chapell								
1	223	.....	313	338	211	.....	.....	.....
Wilks								
1	24	89	130	136	.....	.....	.....	.....
2	71	228	226	262	130	.....	.....	.....
3	75	231	227	208	.....	.....	.....	.....
Allen								
1	72	371	300	318	.....	.....	.....	.....
Storey								
1	94	370	332	.....	.....	.....	.....	.....
Average number of plants in all experiments	131	242	210	199	153	148	272	254
Increase over comparable check	.....	117†	100†	90†	30†	7	11	26

* Average number of plants in three counts (replications).
† Significant increase over check.

Statistical study of the data obtained in these tests shows that significant increases in stand over the checks were obtained from the use of copper-sulfate soak, red oxide of copper, copper carbonate, and even copper-lime dust 24–76. The soak treatment, however, gave significantly better stands than did any of the other methods. Both copper carbonate and copper oxide gave significantly better results than did copper-lime, but the results with copper oxide were not significantly better than those with copper carbonate. Horsfall (1932 b) determined from extensive tests that red oxide of copper controls damping-off of tomatoes better than does copper carbonate.

TABLE 7. YIELDS OF SPINACH, IN BUSHELS PER ACRE,* FROM SEED TREATED IN DIFFERENT WAYS FOR DAMPING-OFF CONTROL† IN GENESEE AND ORLEANS COUNTIES, 1932

Cooperator and plot number	Check	Copper-sulfate soak	Red oxide of copper	Copper carbonate	Copper-lime dust 24–76	Copper-sulfate monohydrate dust	Semesan dust	Semesan liquid
Teubner								
1	483	500	.....	.....	.....	249	.....	.....
2	371	724	.....	.....	.....	464	464	471
3	302	351	465	.....	377	.....	305	309
4	404	322	468	322	.....	.....	.....	510
5	230	384	294	279	283	251	.....	.....
6	608	613	623	631	678	653	.....	.....
7	155	4 5	341	360	204	232	.....	.....
Parker								
1	278	397	398	355	560	349	.....	.....
2	226	296	297	280	380	275	.....	.....
Wilks								
1	129	592	478	659	.....	.....	.....	.....
2	413	834	779	759	.....	.....	.....	.....
3	326	722	723	684	517	.....	.....	.....
Clark								
1	170	493	447	402	147	.....	.....	.....
Winsinger & Chapell								
1	681	.....	910	692	576	.....	.....	.....
Allen								
1	398	484	.....	.....	.....	.....	.....	.....
2	139	709	509	509	.....	.....	.....	.....
Average number of bushels in all experiments	341	516	538	509	442	356	369	413
Increase over comparable check	.....	216‡	214‡	194‡	81‡	2	39	62

* 22 pounds of spinach to a bushel.
† Average of three counts.
‡ Increase significant.

In yields, the copper-sulfate-soak and copper-oxide-dry treatments again gave by far the best results. All four treatments resulted in significantly better yields than those on the untreated plots, and the copper-sulfate-soak treatment was significantly better than the copper-carbonate and copper-lime treatments. Copper oxide gave results significantly better than did copper lime, but the differences between the red oxide and both the copper carbonate and the copper-sulfate soak were not statistically significant.

In one test, yellow oxide of mercury gave as good a stand as did copper oxide but not so good as did the copper-sulfate soak. In a few other scattered trials, a soak in mercuric chloride at 1/1000 for an hour failed to come up to the copper-sulfate soak at 1 ounce to 1 gallon for one and one-half hours. Semesan, both wet and dry, was included in three tests, but owing to the small amount of damping-off in the checks the results were not significant.

COST OF TREATMENTS

Copper sulfate, even in small lots, costs less than 10 cents a pound, which is enough to make up 16 gallons of solution in which 150 pounds of seed may be soaked, 75 pounds at a time. This makes the cost per acre, if 20 pounds are sown, about 1 cent for material plus the cost of a man's time while attending to the drying of the seed. This time will be nearly the same whether he dries 10 or 100 pounds. Thus the cost for this method is probably less than 15 cents an acre.

When the dry copper oxide is used, the cost for material is higher but less time is consumed. Cuprous oxide can be bought at 40 to 75 cents a pound, depending on the quantity and the quality. One pound will treat from 60 to 70 pounds of spinach seed, or enough for 3 to 5 acres. The cost of labor for treating is very low, as only a few minutes are required, and so the total cost is probably less than 25 cents an acre. Certainly the cost of treating spinach seed with either of these copper compounds should not deter any grower, canner, or seedsman from trying one or the other.

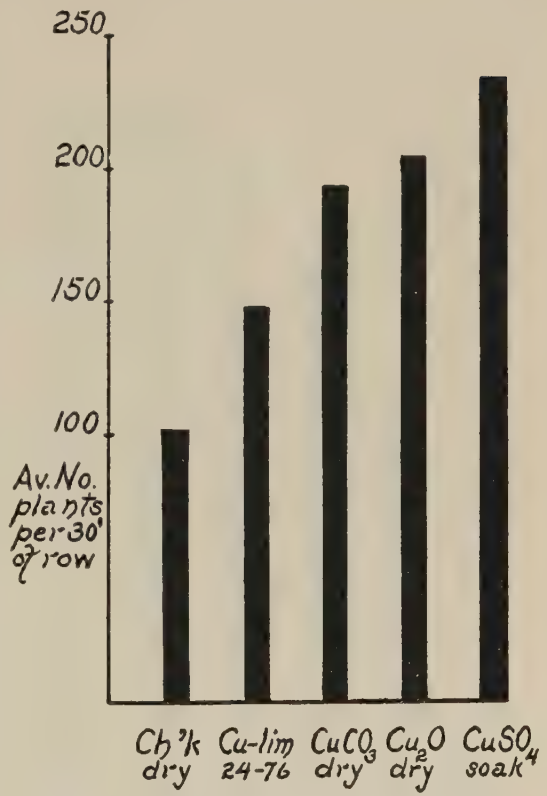


FIGURE 11. CONTROL OF PRE-EMERGENCE DAMPING-OFF BY SEED TREATMENTS, AS MEASURED BY THE RELATIVE STANDS OF HEALTHY SEEDLINGS APPROXIMATELY TWO WEEKS AFTER SOWING

(Averages of 17 muck-land-farm tests in Genesee and Orleans Counties made by Stuart in 1932)

As a matter of fact, in the case of growers who have been in the habit of sowing an extra quantity of seed to insure a satisfactory stand, the reduction to a normal rate of sowing will often save them more than the cost of treatment. Some growers on the muck lands have been sowing 30 pounds of spinach to the acre, when 20 pounds of treated seed would have been sufficient.

OTHER MATERIALS TRIED AND DISCARDED

The three next best dust treatments, after copper-sulfate soak and red oxide of copper dry, were found to be copper carbonate, Semesan, and copper-sulfate monohydrate. It is difficult to say definitely which of these is the best, since they were not directly compared in a sufficiently large

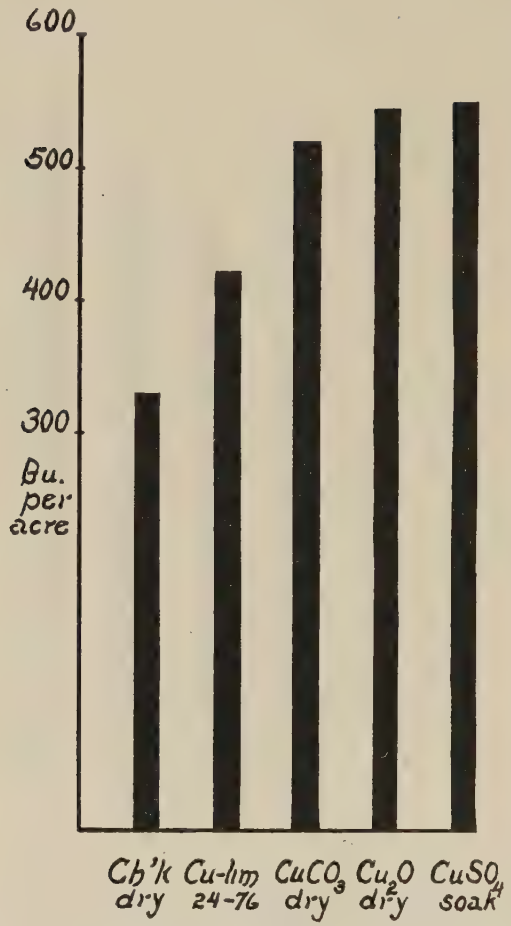


FIGURE 12. RELATIVE EFFECTS OF FOUR SEED TREATMENTS ON DAMPING-OFF CONTROL, AS REFLECTED IN THE YIELDS OF FRESH-CUT SPINACH IN BUSHELS (22 POUNDS) PER ACRE

(Averages of 16 muck-land-farm tests in Genesee and Orleans Counties made by Stuart in 1932)

number of tests. Probably copper carbonate would rate the highest, because of its low cost, its good adherence to the seed, and its availability to the trade. Yellow oxide of mercury was tried once, with good results, and calomel was found to be of some value in two tests; but there is no good reason for using these poisonous compounds, when safer and more efficient ones are available at lower cost.

EFFECT OF THE COPPER SEED TREATMENTS ON OTHER PLANT DISEASES

Coons and Stewart (1927) state that the copper and mercurial treatments used for beet seed in general were beneficial in controlling the root rots which developed late in the beet crop. Our observations on spinach indicate that control of spinach mildew is doubtful, even with the one-hour soak in 1-per-cent copper sulfate. There is a possibility that seed-borne celery blights may be controlled more or less by the red-oxide treatment, but the copper-sulfate soak is too injurious to celery. Therefore, until data have been obtained proving the contrary, growers should not assume that the two treatments recommended for damping-off can take the place of other seed treatments for specific diseases such as blackleg and black rot of crucifers, celery blights, angular leaf spot of cucurbits, bacterial canker of tomato, and the like.

DISCUSSION

During the seasons of 1931 and 1932, through the activity of P. P. Pirone and members of the Nassau County Farm Bureau, more than 10,000 pounds of spinach seed were treated on Long Island by the two copper treatments recommended. One seedsman now advertises that he sells only treated spinach seed. Similarly, three or four canners in western

New York, after seeing field demonstrations, have adopted the practice of giving out only treated seed to their growers.

The question naturally arises in the minds of many thoughtful persons, as they hear of the successful control of damping-off by merely treating the seed, how does this simple process afford protection to a seedling after it has emerged from its seedcoat? The subject has been discussed by Horsfall (1930 and 1932 a), and by Clayton (1931). Current thought runs along two lines. One is that the seedling absorbs enough ionic copper to become at least temporarily resistant to the attacks of the excessively copper-sensitive fungi, to which group the Pythium in question belongs. The recent perfection of delicate chemical technic, and the finding of increased amounts of copper in plants variously treated with copper fungicides, lend support to this theory of seedling protection.

There is some evidence that treating seeds with copper fungicides increases the quantity of other salts found within the seedling plant. These too may have a bearing upon its power to resist fungus attack. On the other hand, watering the seedlings with dilute copper-sulfate solutions has failed to control damping-off as effectively as does seed treatment, and often injures the plants. This may simply point to the importance of very early protection to the seedling while it is emerging from the cracked seedcoat.

The second theory is that the fungicide applied to the seedcoat imparts its toxic properties to the soil immediately surrounding the seed and the young seedling, thereby warding off or turning back the strangling threads of the fungi as they grow toward the seedling. This theory seems tenable in the case of a soluble salt such as copper sulfate, for there is plenty of moisture usually present in the vicinity of the seed to absorb the fungicide. Many fungicidal salts possess a considerable affinity for the organic matter of the soil. The less soluble salts, such as cuprous oxide and copper carbonate, may be slowly acted upon by the soil acids or by the fungi themselves, and thus be gradually changed over to a toxic state. In the case of seeds which are gradually pushed up to the surface of the soil, minute traces of the fungicide are rubbed off, and thus the hole formed by the growing hypocotyl is lined with a protective coating. The authors have obtained photographic evidence that, in the case of spinach treated with red oxide of copper, the seedling receives a coating of the fungicide in this manner from the soil (figure 13).

In any case, seed treatments such as are described in this bulletin do something more than merely disinfect the seedcoats. Clayton (1931) has pointed out that the hot-water treatment of cabbage seed would do as much as that, but it failed to protect against damping-off, while Uspulun and Semesan and copper sulfate gave marked protection.

It is of interest to note here that Godbout (1930) recently obtained marked increases in stand from seed treatment with organic mercurials against *Pythium de Baryanum* in the case of cucumbers, muskmelons, and spinach, fair results with the crucifers, and indifferent results with carrots, onions, and lettuce. Horsfall (1932 b) also reported red oxide as being more or less beneficial to tomato, eggplant, pepper, spinach, cabbage, and even celery.

Although spinach and tomato are the crops which have received the most attention by the writers since the discovery of the red-oxide treat-

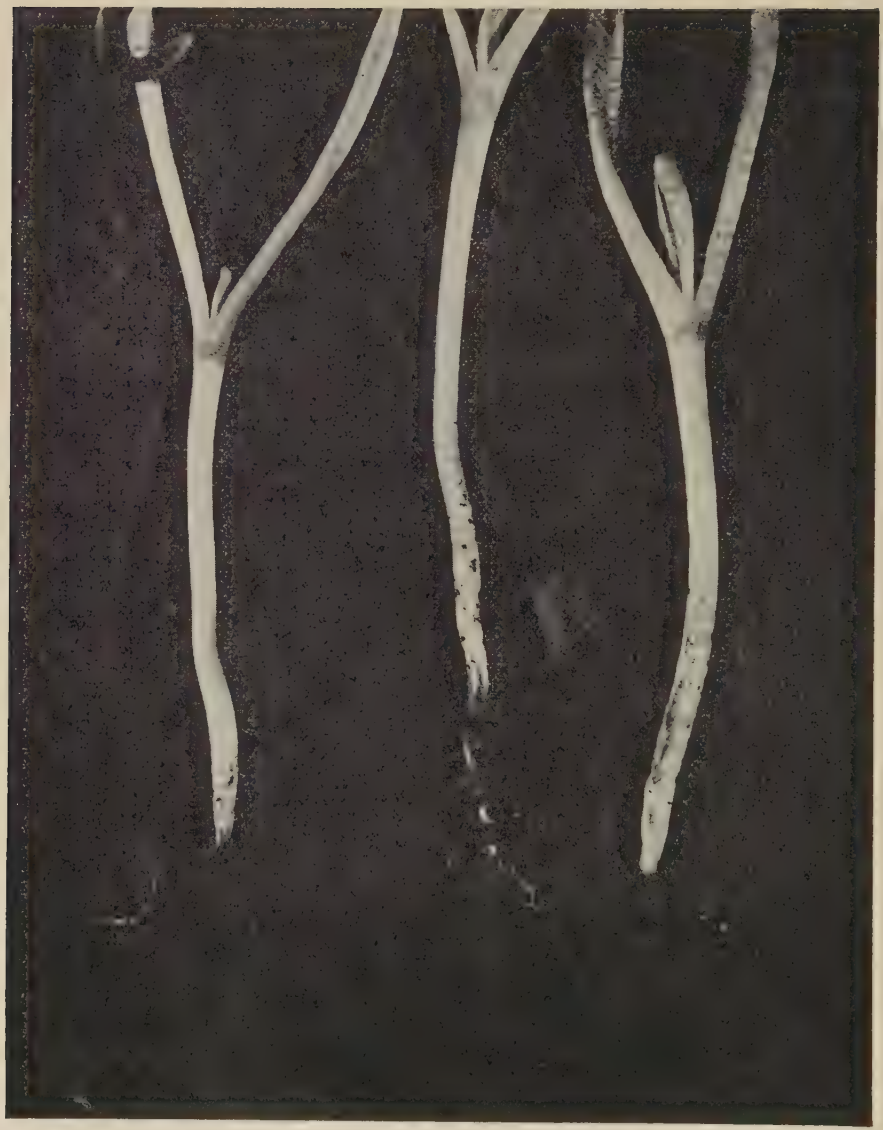


FIGURE 13. SPINACH SEEDLINGS FROM SEED TREATED WITH RED OXIDE OF COPPER (THE TWO ON RIGHT), SHOWING PARTICLES OF THE OXIDE ADHERING TO THE HYPOCOTYLS

This fairly common phenomenon may account in part for the protection afforded the seedling after emerging

ment by Horsfall in 1931, it would seem from their experiments that great benefit to beets might be safely anticipated. Sufficient work has been done by Coons and Stewart (1927) and by McWhorter (1927) to demonstrate the protection that can be expected from treating beet seed with copper carbonate, Semesan, and various other organic mercurial fungicides. These workers found, in both Michigan and Virginia, that a species of Pythium was largely the cause of damping-off of beets.

Coons and Stewart state, in summing up the work of several years:

> All of the tests are consistent in showing that mercury and copper compounds not only reduce the diseases arising from a seed source, but have more or less value in a protective action against diseases arising from the soil.
>
> . . . . . .
>
> Copper carbonate, 18 per cent, and copper sulphate-lime (50–50) dusts have given consistently fair control of disease and fair stands.
>
> . . . . . .
>
> Wet treatments are impractical for commercial use because of the difficulties inherent in drying the seed in quantity. The mercury dusts seem too costly to be practical.

The writers' experiments with spinach and more limited ones with beets have led to similar conclusions. And the superiority of red oxide of copper over the other dry copper compounds in all their tests cannot but revive the hope that here is indeed a better treatment for beet seed.

PRACTICAL SUGGESTIONS

Some growers make a practice of soaking their seed overnight in water to hasten germination. From a few limited tests it appears that spinach seed may be safely soaked for twelve hours in dilute copper-sulfate solution, thus killing two birds with one stone. However, since only a very limited number of experiments of this kind have been made thus far, growers are cautioned not to follow the practice without making a preliminary test. Tomatoes and beets also seem to be uninjured by soaking overnight in the copper-sulfate solution.

It has been shown that even a fifteen-minute soak is much better than none at all, and so growers are urged not to neglect the practice of treating because of lack of time.

The seed should not be rinsed after either of the treatments outlined in this bulletin.

Seed may be treated weeks in advance of sowing, but, in case the wet method is employed, care must be exercised to dry the seed thoroughly before storing it.

If the seed is soaked in copper-sulfate solution and sown as soon as it is dry enough to pass through the drill, allowance must be made, in setting the drill plate, for swelling of the seed. Usually the next size of hole in the drill plate is used when the seed is sown on the same day that it is treated. Thus, if dry seed is normally sown in hole 5 or hole 6, then soaked seed should probably be sown in hole 6 or hole 7, depending somewhat on the variety, the size of the seed, and the kind of drill used.

From preliminary tests made on many other vegetables, it seems that the red-oxide-of-copper treatment is safer to use than the copper-sulfate soak. Celery, lettuce, onions, and the crucifers are decidedly injured by

the wet treatment. Other vegetables also are probably injured. This matter is receiving special attention, and the results of study on it will be published at an early date. At this time the vegetables that appear to be benefited most by red oxide of copper include spinach, beet, chard, tomato, eggplant, pepper, pea, cucumber, squash, lima bean, and melon.

For small quantities of seed, as for gardens and greenhouses, the red-oxide treatment is favored by the authors, but the best amount to be used for each kind of seed will have to be decided by an extensive series of experiments now in progress. There are approximately 65 level teaspoonfuls of cuprous oxide in a pound, or enough for 65 to 70 pounds of spinach seed. A convenient way to measure enough for an ounce of seed is to pour a level teaspoonful of dust on a piece of paper, make a symmetrical pile and divide it into four equal parts with a knife, and then in a similar manner divide one of these quarters into four equal piles, using one of these smaller portions for the ounce of seed.

For large quantities of seed such as canners and seedsmen would have, the cuprous oxide can best be applied in some kind of crank- or motor-driven mixer. A barrel churn makes a suitable one. A dust mixer such as is used for the home mixing of celery or potato dust also can be employed.

A good grade of cuprous oxide suitable for seed-treating purposes has not been so easy to procure on the market as has copper sulfate. There are a number of inferior grades available, with varying amounts of the black cupric oxide mixed with the bright red cuprous oxide. But these are to be avoided. County agricultural agents in New York have been warned of this situation, and have been supplied with a list of firms that agree to carry a satisfactory grade for the trade. Growers should insist on a bright red product (close to Eugenia red in Ridgway's color standards), free from appreciable amounts of cupric or black oxide of copper. One that fumes on being shaken in a bottle, which shows it to be dusty, dry, and practically free from oil, is to be preferred.

A word of caution is in order against confusing the red oxide of copper advocated here with either the red or the yellow oxide of mercury, one of which has been attracting attention of late as a treatment for potato seed. These mercury dusts are very injurious to many vegetable seeds.

SUMMARY

Both the muck and the upland soils of the State seem to harbor damping-off organisms which at times cause excessive reductions in the stands of spinach. *Pythium ultimum* has been found to be the one most frequently associated with the disease, and its pathogenicity has been proved.

Excellent control has been obtained in the greenhouse and in the field on both types of soil by treating the seed with copper or mercurial fungicides. The best results were obtained by either soaking the seed for an hour in approximately a 1-per-cent solution of copper sulfate, or shaking the seed with cuprous oxide powder until it was thoroughly coated, using 1 level teaspoonful of powder to 1 pound of seed, or 1 pound of powder to 65 pounds of seed.

The average increase in yield from the two best copper seed treatments, on more than 20 farms in 1932, amounted to more than 2 tons, or more than 200 bushels, of fresh-cut spinach to the acre.

Other seed treatments which gave somewhat less satisfactory results included copper carbonate, Semesan, copper-sulfate monohydrate, calomel, and mercuric oxide, all in the dry form, and mercuric-chloride solution.

A number of other vegetables have responded very favorably in preliminary tests to the two best copper treatments, especially to the red oxide of copper. These include beet, chard, cucumber, melon, squash, tomato, eggplant, pepper, lima bean, and pea.

The cost of treating spinach seed for an acre of spinach (20 pounds) does not exceed 25 cents.

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